to all his projects. There can be no doubt that Angola, to the elucidation of the natural history of which Mr. Monteiro contributed so largely, still presents a fine field for the collector, and it is to be hoped that some one will be found who will continue the researches so well instituted by the deceased traveller.

SOUND COLOUR-FIGURES

THE great interest excited by Prof. Bell's telephone and Mr. Eddison's phonograph, in which an elastic disc or membrane faithfully takes up the highly complex vibrations due to sounds of the human voice, has directed renewed attention to the optical methods hitherto employed in studying the motion of resonant media. These have, in important instances, been based on observations of the secondary effects produced by sonorously vibrating bodies. Thus Chladni watched the behaviour of sand strewn upon sounding plates and membranes; König that of gas flames acted on by aërial vibrations. The present article describes an analogous method depending on the colours reflected from slightly viscous liquid films when thrown into sonorous vibration.

The ordinary phenomena called the "colours of thin plates" are sufficiently well known, but a short description of them, taken from a standard work on Physical Optics, may still not be out of place here as a reminder.

"If the mouth of a wine-glass be dipped in water, which has been rendered somewhat viscid by the mixture of soap, the aqueous film which remains in contact with it after emersion will display the whole succession of these phenomena. When held in a vertical plane, it will at first appear uniformly white over its entire surface; but, as it grows thinner by the descent of the fluid particles, colours begin to be exhibited at the top, where it is thinnest. These colours arrange themselves in horizontal bands, and become more and more brilliant as the thickness diminishes; until finally, when the thickness is reduced to a certain limit, the upper part of the film becomes completely black. When the bubble has arrived at this stage of tenuity, cohesion is no longer able to resist the other forces which are acting on its particles, and it bursts."—(Lloyd's "Wave-Theory of Light," p. 100.)

If the film, instead of remaining at rest, is thrown into sonorous vibration, totally distinct colour-phenomena instantly present themselves. A rough idea of their general character may be obtained without the aid of any apparatus as follows. While washing the hands, after getting a good lather, a film can easily be formed between the thumb and forefinger of one hand held in a horizontal plane; the other hand supplies an extemporised tube through which a note can be sung, and so vibrations caused to impinge on the *lower surface* of the film.

If this is done the reflected colours will be seen to be in regular motion, and, in particular, a number of small eddies of colour will be observed whirling about fixed centres of rotation. Steady coloured bands may also be sometimes recognised, but with much greater difficulty.

Fixed bands and stationary vortices form, in fact, the constituent elements of all the sound colour-figures obtainable by film-reflection.

In order to study these in detail a specially arranged apparatus is, of course, requisite. I have found the following give excellent results.

An L-shaped cylindrical brass tube is permanently fixed upon a wooden stand, with its two limbs vertical and horizontal. The vertical limb terminates in a narrow flat circular ring. The open orifice of the horizontal limb is fitted into a caoutchouc tube of equal bore, ending in a trumpet-shaped mouth-piece. For the purpose of supporting the films operated on, I use a series of metallic discs pierced with apertures of various shapes and sizes. On covering one of these, by means of a camel-hair brush, with some weak solution of soap,[1] a film of considerable durability will be formed upon it. The disc should first be held in a vertical plane until the coloured bands have begun to show themselves, and then laid gently upon the horizontal ring prepared for its reception. The observer places himself so as to get a good view of the assemblage of colours reflected by the film, and the instrument[2] is ready for use. Sounds of tuning-forks, whistles, organ-pipes, &c., or notes of the human voice have only to be produced near its mouthpiece, in order that their vibrations may be conducted to the film, and the resulting phenomena observed.

The forms thus presented are of endless variety and great beauty. They almost invariably include both motionless curvilinear bands of colour very regularly disposed, and also a system of colour-vortices revolving about fixed nuclei. The contrast between the steady and moving portions of the figures is always very striking, and the effects of changing tint which accompany the progressive thinning of the film gorgeous in the extreme. When the moment of its dissolution is close at hand, patches of inky blackness invade the field, until at last there is sometimes nothing left but an ebony background, with here and there a few scraps of light, either at rest or still flying round their former orbits, the remnants of fixed bands and whirling vortices.

That the results obtainable by the mode of experimenting above described are likely to present a practically endless variety of form, will be at once obvious from an enumeration of the several causes which may influence the assemblage of colours reflected at a given instant from a given film acted on by the vibrations of a given sound. These are:—1. The shape of the film; 2. Its size; 3. Its consistency; 4. The intensity of the sound; 5. Its pitch; 6. Its quality; 7. The direction in which the sound-vibrations take place with reference to the plane of the film.

It thus appears that each colour-figure observed *may* be a function of not less than seven[3] independent variables; and on experiment this proves to be the fact. An alteration made in any one of these elements, while all the rest are kept constant, produces a corresponding change in the appearances observed. The intensity of the sound does not, it is true, affect the form of the figure, but controls the rate of its vortical motion; the louder the sound the more rapid the rotation of the colour-whirls. All the other elements act directly on form.

It is evident from what has preceded that an attempt at anything like a general classification of sound colour-figures would afford materials for a considerable volume. All that can be done within the present narrow limits is to draw attention to a few points of special interest.

Dependence of Form on Pitch.—This is perhaps most distinctly shown by alternately stroking with a resined bow two mounted tuning-forks of different pitch, the open ends of whose resonance-boxes are placed close to the mouthpiece of the Phoneidoscope. As long as the same aperture is used, and the film kept at one degree of consistency by frequent renewal, each note will instantly call forth its own colour-figure for any number of alternations. This mode of experimenting has the advantage of giving perfectly steady and sharply defined figures. But the successive alterations of form due to changing pitch are more interestingly shown by singing[4] the diatonic or chromatic scale, on some single vowel, into the Phoneidoscope. The complete change of figure consequent on

[1] Castile soap, I find, answers extremely well.

[2] It is manufactured and sold under the title of the "Phoneidoscope," by S. C. Tisley and Co., Philosophical Instrument Makers, 172, Brompton Road, S.W.

[3] A reader of Helmholtz will see that I might have added an eighth element by taking into account differences of phase among partial tones, which, though inoperative on quality, directly affect mode of resultant vibration.

[4] A pitch-pipe with a sliding piston may be substituted for the voice in this experiment.

perhaps but a semitone's alteration of pitch, is often most surprising. It was these sudden kaleidoscopic bounds from one form to another which suggested the name given to the observing instrument. In general the complexity of the figure increases with the acuteness of the exciting sound. With low notes a comparatively simple arrangement of a few rings and pairs of vortices occupies the film. As the pitch rises, the separate parts of the figure diminish in size and increase in number, so that the whole field is covered with a regular pattern which is constantly growing more and more minute. With very shrill sounds the pattern can only be made out by using a magnifying-glass.

Effects of Quality.—These are easily observed by employing unison organ-pipes of different *timbres*, *e.g.*, treble C's belonging to stopped and open diapasons, claribella, and hautbois, respectively. By sounding them consecutively in the above order, figures rapidly increasing in complexity are obtained.

Prominent among differences of quality are those which distinguish vowel-sounds of the human voice sung successively on one and the same note. Marked corresponding differences of colour-figure are recognisable in many instances, but I have not at present succeeded in extending the observation to *all* the European vowel-sounds.

Effects due to Direction of Vibration.—The best mode of observing these is to strike a tuning-fork, and hold it with one of its prongs *close* to the surface of the film.

By moving the fork it is easy to show that both the axis of symmetry, and to some extent also the form, of the colour-figure thus produced, are dependent on the position of the fork with respect to the film, and therefore on the direction in which the exciting vibrations impinge upon it. The steady bands of a figure obtained by this method shift to and fro upon the film in obedience to the fork's movements, almost as though under a magnetic influence resident in its prongs.

Resultant Figures due to Combined Sounds.—If the sounds of two tuning-forks are separated by a considerable interval of pitch, say an octave, they will generate, when alternately applied to the same film, very different figures. When both are applied together there results a figure different from either of those due to each fork by itself. It is in fact a compromise between the two. In order to convince himself of this the experimentor should first get the forms of the component figures well into his memory by repeatedly producing them, and then watch the effect, *on some one band in either figure*, of mixing the two sounds in various degrees of relative intensity. Let us suppose that fork 1 produces figure 1, and fork 2 figure 2, respectively, and that a band in figure 1 is selected for observation. Then if fork 1 be struck sharply, and fork 2 weakly, the band will alter its form so as to exhibit a slight approach to the arrangement in the corresponding part of figure 2. As the note of fork 2 is more loudly sounded this approach will be more decided. If fork 2 is made preponderant the result will be the arrangement of Fig. 2 with some modification towards that of figure 1. The same thing holds good for the rotating portions of the figures. Complex colour-flows are seen to result from a compromise between simpler component vortices.

Effect of Beats.—When two sounds of very nearly the same pitch coexist, slow fluctuations of intensity called "beats" are known to be produced. If a film is exposed to the simultaneous action of two sounds so related, the fixed parts of the resulting figure take up a swaying motion about their mean position, each complete oscillation synchronising exactly with one entire beat. The vortices show, in general, an increased speed of rotation during one half of each beat, and a diminished speed during the other half. But in particular cases a bolt forward every alternate half-beat seems to be followed by intermediate quiescence, or the direction of motion may be actually reversed, so that a vortex rotates positively during one half-beat and negatively during the next.

Representation of Dissonance.—When the beats become too rapid for separate recognition, and coalesce into the effect which we call discord, the colour-figure presents a tremulous appearance, like that shown by the tip of a singing gas flame. Prof. Helmholtz has remarked how unpleasant is the impression which a flickering light makes upon the eye, and pointed out its analogy to the effect of rapidly intermittent sounds on the ear. In the present experiment, acoustical and optical dissonance are exhibited in a direct and interesting connection.

As the phenomena described in the above article admit of such facile reproduction in all their beauty of form and splendour of hue, I have thought it needless to attempt illustration by diagrams, which could convey but an inadequate notion of the former, and none at all of the latter.

SEDLEY TAYLOR

Trinity College, Cambridge, March 6

REFLECTION OF LIGHT[1]

PLACE the heliostat in position, and bring a slender beam of light into the darkened room. Then get a small looking-glass, or hand-mirror, and a carpenter's steel square, or a sheet of stiff paper, having perfectly square corners. Hold the mirror in the beam of light. At once you see there are two beams of sunlight, one from the heliostat and another from the mirror. Hold the glass toward the heliostat, and you will see this second beam going back toward the window.

This is certainly a curious matter. Our beam of light enters the room, strikes the mirror, and then we appear to have another. It is the same beam, thrown back from

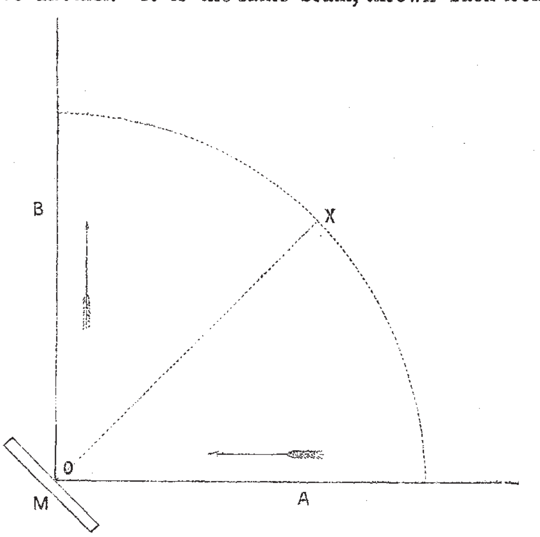

FIG. 1

the glass. This turning back of a beam of light we call the reflection of light.

Place a table opposite the heliostat, and place the mirror upon it, against some books. Turn the mirror to the right, and the second or reflected beam of light moves round to the right. Turn the glass still more, and the beam of light will turn off at a right angle, and there will be a spot of light on the wall at that side of the room. Now bring the carpenter's square or the piece of square paper close to the mirror, so that the point or corner will touch the glass just where the sunlight falls upon it. Now

[1] From a forthcoming volume of the "Nature Series"—"Light: a Series of Simple, Entertaining, and Inexpensive Experiments in the Phenomena of Light, for the Use of Students of Every Age," by Alfred M. Mayer and Charles Barnard.